# Economic Development and the Accumulation of Know-how

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Economic development depends on the accumulation of know-how. The theory of economic growth has long emphasised the importance of something called technical progress, but what that is, and how it grows has not been well elucidated. Technical progress is really based on three separate aspects: tools, or embodied knowledge, recipes or blueprints or codified knowledge and know-how or tacit knowledge. While tools can be shipped and codes can be e-mailed, know-how exists only as a particular wiring of the brain and as such it is hard to move around. That is why the growth of know-how can easily become the binding constraint on the development process.

This means that an important implication of the growth of know-how has been ignored. It is our brain's capacity to do things that we are not fully conscious of, and that we do not understand, even conceptually, but we know how to do. For example, we know how to walk but we do not really understand what we do in order to walk: which muscles we move and how we keep our balance. As a consequence, we do not transmit the ability to walk by talking about it to our children. They learn from imitation and repetition over a protracted period of time, just as they learn to play an instrument or to speak a language. Transferring tacit knowledge or know-how, is more difficult and generally takes longer than passing on objective knowledge.

Such know-how can only grow at the society level through increasing specialisation by individuals. Individuals have a limited capacity to acquire knowledge and know-how because life is limited and learning takes time. Let us call a "personbyte" the amount of know-how that comfortably sits in a brain. This implies that as knowledge and know-how expand, each individual must possess a smaller and smaller proportion of the whole corpus. They become specialised. In some ways a modern person with a detailed knowledge of an obscure subject cuts a less impressive figure than an Eskimo who knows how to fish and feed himself, how to build his own igloo and generally has all the skills needed to survive in a hostile environment. The modern person by contrast cannot make his own clothes, does not know how to hunt or butcher his own meat or how to manufacture the computer he works with. Yet the society of the modern person is much richer and more productive than that of the Eskimo because it knows how to do more things and do them more efficiently.

Adam Smith's pin factory required increased specialisation of tasks; the same specialisation is required of know-how. As economic development proceeds, societies acquire the capabilities to make more and more complex products. This means that the other side of the coin of individual specialisation is the fact that production requires teamwork and co-operation among larger and larger numbers of people. A clay pot is a more complex product than a stone-age axe but the knowledge required to produce it could reside within a single brain. A modern jet airliner is made up of thousands of components some of great complexity in themselves. Its production is spread across scores of companies that employ the know-how of thousands of individuals. It is a characteristic of developed economies that they have the know-how to make such complex products. Indeed development may be seen as exactly the acquisition of more and more know-how together with the arrangements to combine and recombine it to make complex products. Think of units of capability as elements of practical knowledge. The more such capabilities a society has, the richer it can be.

There is an analogy with the game of scrabble. Individual elements of know-how or capabilities are like letters in the game. Products are like words. With three letters you can make rather few words. Double the number of letters and you much more than double the number of potential words because the letters can be combined in many different ways. You can also potentially make 6 letter words, i.e. more complex products. The 26 letters of the Roman alphabet can make all the words in the dictionary which number in the hundreds of thousands.

Of course in a world of international trade, the know-how that can be embodied in goods and services can be effectively imported as machines or intermediate inputs that can be used to produce locally. If they can be brought in from other places, these elements will not restrict what can be produced in a given place. But for production to take place there, beyond intermediate inputs or machines, capable teams must be assembled in place and what teams can be put together will be limited by what know-how exists there.

Adam Smith remarked that specialisation was limited by the extent of the market. Since products can be exported to the whole world, the scope for specialisation is considerable. Places will never be able to have the know-how to do everything. But they can acquire the things they do not know how to do by trading for the things that they do know. As a consequence, the nature of the goods that can be done in a place and sold elsewhere have an outsized effect on the prosperity of that location. In particular, the salaries that the export sector can afford, given its productivity, will impact the salaries that everyone in that location will earn.

That some countries have developed more successfully than others implies that not all capabilities can be acquired through trade or that they move with great difficulty. Some capabilities may reside, for example, in the domestic political system that ensures security and a responsiveness to the requirements of productive co-operation or in the legal system that protects property rights and assures the sanctity of contracts. But the large difference in income within the same country suggests that the issue involves more than just national political institutions.

So our claim is that the accumulation of know-how at the societal level requires larger and larger networks of collaboration to effectively convert that know-how into a greater variety and complexity of production. To substantiate this claim we need a measurement of complexity as well as measures of output and study their relationship across countries and over time. Capabilities cannot readily be observed but there are methods of measuring complexity and know-how indirectly using trade[1] or production[2] data. Countries with lots of know-how should have a comparative advantage in the production of many different products rather than just a few. They should also have a comparative advantage in the production of complex products. Given a hierarchy of countries in terms of complexity, one would expect that the most complex products would be produced by relatively few countries - those at the top of the hierarchy. Moreover one would expect a strong positive correlation between the ranking of countries in that hierarchy and their ranking by GDP per head.

We define comparative advantage in a particular way, following Balassa

(1986). We say a country has a revealed comparative advantage (RCA) in producing a given product if that product is a greater proportion by value of the country's exports than its share of total world trade[3]. Using detailed disaggregated trade data we see how many such products there are among a country's exports. If we arrange countries as the rows and the products as the columns of a matrix, we can enter a 1 for each product where a country has a comparative advantage and a zero otherwise. Each row sum then gives the number of such products for each country and is a measure of the diversity of each country's competitive advantage. Meanwhile the column sums tell us how many countries have a comparative advantage in a given product. The larger the column sum the more ubiquitous a product is and the less complex we would expect it to be. Products with low ubiquity will be one of two sorts: they could be products of great complexity or they could be naturally rare, like certain mineral resources such as gemstones. The two cases can be distinguished however because complex products will be produced by few countries and those countries will be highly diversified. Countries that are not diverse but which produce a rare export are generally producers of rare commodities.

An interesting feature of this matrix of comparative advantages is that it has a triangular structure. That is some countries have very diverse comparative advantage. They produce competitively many products. Other countries have many fewer products where they are competitive. This is the pattern we would expect if a country with capabilities makes all the products that are feasible with these capabilities. That goes against the grain of much of classical trade theory which predicts specialisation on the basis of comparative advantage and which would lead to the RCA matrix having a block-diagonal structure. In fact the RCA matrix suggests there is little specialisation even at the level of over 5,000 products[4].

We measure complexity not simply by diversity but by weighting exports where there is a comparative advantage both by their rarity value (the inverse of ubiquity) and by how far they are exported by other diverse countries with scarce exports. An index of complexity is obtained by an operation on the matrix which combines all that information to produce adjusted row sums after a series of iterations[5]. We call the resultant quantity for each country the economic complexity index or ECI[6].

Now when we derive such an index and run a cross-country regression on GDP per capita, we do indeed find a compelling association. This association is that much stronger if we control for natural resource wealth as captured by a country's exports per capita of mineral resources (See Figure 1). However, this association is more than just a static relationship. If we regress the growth in per capita income over 10-year periods on economic complexity, controlling for the initial income level and for any increase in natural resource income over the period we find that initial complexity explains future growth. Countries with a higher ECI than their GDP per head would lead one to expect tend to grow faster in the decade after the date of the regression data, while those with a low CDI relative to GDP tend to grow more slowly. The ECI explains over a third of the variance explained by the equation and an increase of one standard deviation in complexity is associated with a subsequent acceleration of a country's growth rate of over 1 ½ per cent a year (Hausmann et al. 2014).

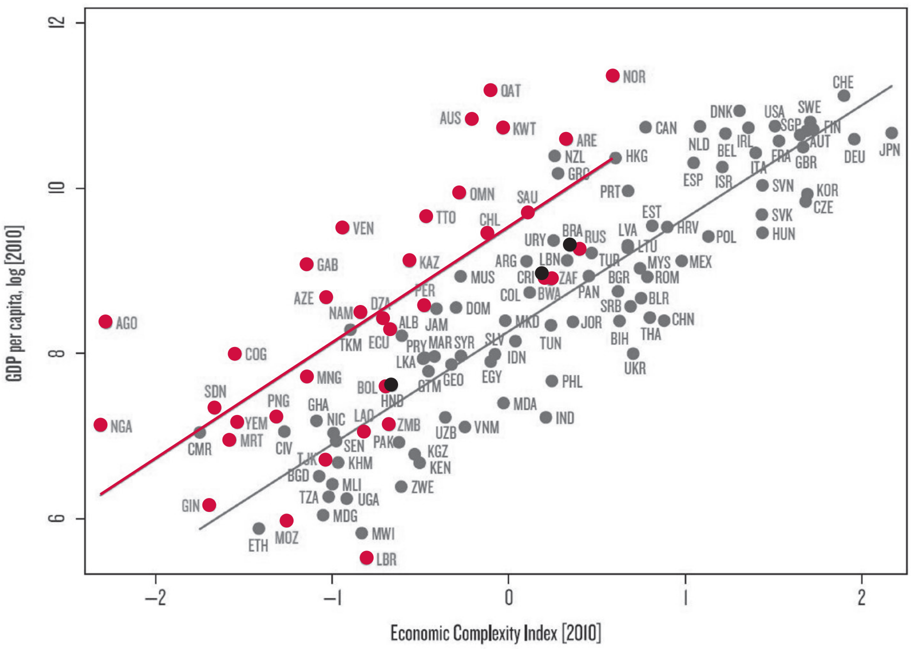
Indeed we find the ECI has better predictive properties than other measures like the World Bank's measures of quality of governance or the World Economic Forum's Global Competitiveness Index.

Figure 1 shows the relationship between income per capita and the Economic Complexity Index (ECI) for countries where natural resource exports are larger than 10% of GDP (red) and for those where natural resource exports are lower than 10% of GDP (blue). For the latter group of countries, the Economic Complexity Index accounts for 78% of the variance. Countries in which the levels of natural resource exports are relatively high tend to be significantly richer than what would be expected given the complexity of their economies, yet the ECI still correlates strongly with income for that group.

This reinforces us both in the view about the nature of economic development and in the usefulness of our data proxies. It raises questions however. What are the implications? Would this information enable us to refine development policy? To pursue those questions, we note that products differ not only in their complexity but in their relationship to one another. We can conceptualize a product space as a space in which products have differing relationships to other products, just as trees in a forest are at different distances to other trees.

It is possible to draw up a map of the product space, using the trade data and to locate a country's positioning within it. We infer the similarity in the capabilities required to produce two

**Figure 1: Economic Complexity and per capita income, 2010**




Source: Hausmann et al., 2014.

products by looking at the probability that they are co-exported. Proximity of products is measured by the conditional probability that a country exports one product given that it exports the other. "Exports" in this context means it has a revealed comparative advantage and an entry of one in the matrix of comparative advantage. Since conditional probabilities are not symmetric, we take the minimum. That avoids errors which can arise from some products being rare. If a product is exported by just one country, for example, all other products exported by that country would have a conditional probability of 1 with respect to the rare product, even though they may be unconnected. However, the reverse conditional probabilities would all be extremely low. We can compile another matrix of minimum conditional probabilities between each pair of products, a matrix of proximities.

This product space has a distinct structure: parts of the product space are very dense and other parts are quite sparse. For example, while machines tend to be complex products, they are also in a dense part of the product space because if you have the capabilities to make one type of machine, those capabilities can be redeployed to make another. This does not happen with either oil or mining products, where the capabilities required are less relevant for other forms of production.

To move into a new product, the country must secure the requisite capabilities. But this poses a chicken and egg or coordination problem. You do not accumulate know-how in things you do not do and it is impossible to do things without the requisite know-how. This dilemma is solved in the real world by diversifying into products that require much of the know-how that already resides in the country in question, so as to minimize the number of missing pieces.

There is an analogy with monkeys in a forest. In colonising the forest, the monkeys jump from a tree they occupy to a neighbouring tree. Remember that the distance between the trees in the forest, i.e. of products in the product space, is related to the similarity in the capabilities they require. Monkeys tend to jump to nearby trees, because far away trees require many capabilities that they do not have, aggravating the chicken and egg problem. If they are in a dense part of the forest they have many options to proceed with colonisation and it is easy to make rapid progress. If they are in an isolated part of the forest where there is a clump of trees separated by distance from the rest of the forest, they face greater coordination problems and progress is more difficult. There is therefore a premium on being in a dense part of the forest. It is better to be in the kind of technologies, that is, to have the kind of know-how which is applicable to many different products (see Hidalgo et al, 2007 for evidence on this process).

These results encompass a number of early attempts to explain trade patterns. If we group products according to factor intensity following Leamer (1984) or group them according to Lall's technological classification (Lall, 2000), we find a generally somewhat higher average proximity within those groups than between them. Those classifications do capture important elements of the relationship among products but by no means all of the characteristics of the product space. Clearly there are other, more specific, factors at work too.

We may suppose that the product space is a structural relationship common to all countries. To locate a country in the product space we just need to know in which products it has comparative advantage. To calculate a measure of the probability that a country will be able to develop comparative advantage in a product it currently is not good at, we can calculate a weighted distance of the products it has comparative advantage in with that target product. Since we take the proximity measure to be reflecting the degree of factor commonality across two products then the probability of a country exporting any product in future should depend on that product's proximity to the current export basket. We can combine the pairwise proximity measures for products with each country's export basket to define density: the density of a country's exports around a particular good. Regression analysis confirms that subsequent comparative advantage in a product is strongly associated with the previous density measure, that is, density is higher in products that were subsequently produced with comparative advantage. Structural change does depend on the topology of the product space.

Knowing the structure of the product space reveals where the best possibilities lie for diversification, which new products might be developed on the basis of existing know-how or with the addition of relatively little extra know-how.

If a country has many capabilities and is in a dense part of the product space, diversification and development might be expected to proceed faster. The opportunities to exploit existing capabilities in new ways will relatively abundant and chicken and egg problems will be less severe. Moreover, the underlying logic of the capabilities model of comparative advantage implies that the more capabilities a country has, the greater the expected benefit from adding another capability.

In fact, we can calculate a measure of the overall position of a country in the product space by adding the densities of all the products it does not currently have comparative advantage in, weighted by their complexity: being close to a complex product is more valuable than being close to a simple one. This measure, which we call Complexity Outlook Index has been shown to also be highly predictive of future growth in complexity and in income per capita (Hausmann et al., 2014).

Adding capabilities is more likely to be profitable and therefore more likely to happen the more capabilities are present in a country and the better the position of the country in the product space. In the fortunate circumstances in which a country has more capabilities than are expressed in its current level of income and is in a dense part of the product space, there may be little need for special government intervention. If growth is not occurring it would be appropriate to look for the constraints that are inhibiting development in what should be a promising situation (Hausmann et al., 2008).

Where a country has few capabilities or is in a peripheral part of the product space, further diversification with existing capabilities may not be possible, while the acquisition of further capabilities may be too expensive for entrepreneurs to undertake in view of the expected returns. The acquisition of capabilities, however, is likely to have larger social benefits than the profits that can be captured by the entrepreneur. This is because the possibility for further recombinations of new capabilities and the fact that the acquisition of a particular capability may make the development of yet another capability more profitable. In those circumstances it would be appropriate for the government to promote the acquisition of key capabilities that would permit further diversification. In directing such support either the government itself or, more likely, the entrepreneur would benefit from having knowledge, tacit or explicit, of the product space. The fewer capabilities a country has, the more likely it is that capabilities could be most easily acquired by encouraging foreign investment that brings in additional capability. We also find that neighbours, migrants, spin-offs and even business travel play an important role in the diffusion of capabilities.

We started with the assumption that know-how is the hardest component of technical progress to be mobilised, and as such can become the binding constraint of the development process. A reinterpretation of this process from the viewpoint of know-how allows us to describe the development process differently and leads us to tools and policy approaches that may enrich the debate of what to do to promote the prosperity of a region or a country.

**Notes**

1. The trade data is disaggregated to SITC 4-digit level. For a demonstration of how a range of different capabilities and their distribution can lead to pattern of comparative advantage in different goods. See Hausmann R. and C.A. Hidalgo (2011).

2. Trade data has the advantage that all countries report it with a standardized classification, while there is more variation in the classification systems used for production data. However, we can use production data to analyse the variation of the complexity of production and income within countries. See for example Hausmann et al., (2014).

3. Let $S_{cp}$ be the share country c has of the world market for product p and $T_p$ be the share of product p in the total world market. Then $RCA_{cp} = S_{cp}/T_p$ since $T_p = \Sigma S_{cp}$
The country has a revealed comparative advantage if RCA ≥ a, some threshold. We take a =1.

4. These trade data are for goods only. We have reason to believe however that adding services, were the data available, would not change the pattern. A study of production data for 347 municipalities in Chile and 700 industrial categories, including services, generated a matrix of industrial production by area. It had the same triangular structure with Santiago producing most products while remote rural areas produced few.

5. If the RCA matrix is denoted as $M_{cp}$, we define Diversity = $k_{c,0} = {}_p\Sigma M_{cp}$ ; and Ubiquity = $k_{p,0} = {}_c\Sigma M_{cp}$. A recursion known as the method of reflections progressively adjusts exports for their ubiquity and adjusts products for the diversity of their exporters.

$$k_{c,N} = \frac{1}{k_{c,0}} \sum_{p} M_{cp} k_{p,N-1}, \qquad [1]$$

$$k_{p,N} = \frac{1}{k_{p,0}} \sum_{c} M_{cp} k_{c,N-1}, \qquad [2]$$

6. The first three recursions have a clear intuitive meaning where diversity has been corrected for ubiquity which itself has been corrected for diversity. After further iterations the process converges to give the ECI and an equivalent product complexity index. For detailed exposition see Hidalgo and Hausmann (2009).

**References**

Balassa, B. (1986). Comparative advantage in manufactured goods: a reappraisal. The Review of Economics and Statistics 68(2) 313-319 http://dx.doi.org/10.2307/1925512

Hausmann, R. et al. (2014). The Atlas of Economic Complexity; mapping paths to prosperity. Section 3.
http://atlas.cid.harvard.edu/

Hausmann, R. and Hidalgo, C.A. (2011). The Network Structure of Economic Output. Journal of Economic Growth

Hausmann R., Klinger, B., and Wagner, R. (2008). Doing growth diagnostics in practice: a 'mindbook'. Harvard CID Working Paper No. 177

Hausmann, R. Hidalgo, C.A., Stock, D.P. and Yildirim, M.A. (2014) "Implied Comparative Advantage" Harvard Kennedy School Working Paper No. RWP14-003.

Hidalgo, C. and Hausmann, R. (2009). The building blocks of economic complexity. Proceedings of the National Academy of Sciences 106; 10570-10575

Hidalgo, C. A., Klinger, B., Barabasi, A.L. and Hausmann R. (2007). The Product Space Conditions the Development of Nations. Science, 317(5837), 482-87 http://dx.doi.org/10.1126/science.1144581 PMid:17656717

Lall, S. (2000). The technological structure and performance of developing country manufactured exports 1985-1998. Queen Elizabeth House, Working paper 44,
University of Oxford

Leamer, E.E. (1984). Sources of Comparative Advantage: Theory and Evidence. MIT Press